

ABSTRACT

Sensitivity of Mars Network Surface Navigation to Timing Errors

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Prepared for the
AAS/AIAA Astrodynamics Specialist Conference
Big Sky, Montana, USA

August 3-7, 2003

Introduction

NASA has embarked on a detailed *in situ* investigation of Mars using landers, rovers, orbiters, and aerobots. A critical component to the success of this campaign is the development of an orbital infrastructure to support the telecommunications and navigation needs of these missions. This infrastructure, called the Mars Network, will be a collection of Mars in-situ science orbiters that can act as relays (as a secondary mission) and, eventually, a dedicated telecommunications satellite. Each of these orbiters will carry a common, reconfigurable UHF transceiver, called Electra that can transmit and receive in-situ communications and navigation data. The first element of the network will be the Mars Reconnaissance Orbiter (MRO) to be launched in 2005 and aerobrake into a 255 x 320 km altitude, Sun synchronous orbit at Mars. Its primary mission is scientific, but with Electra it can also play a critical role in establishing the first node of the network. A key service that the network will provide is the formation of Doppler tracking measurements between a Mars surface asset and a Mars Network orbiter that can be used to determine the location of the surface asset. A requirement of the network is to provide tracking data of sufficient quality to enable position determination to better than 10 m (1σ) uncertainty. Numerous error sources impact the quality of this data, one of which is data time tag errors. That is, the orbiter maintains a time reference that it uses to tag the data upon collection. The difference in time between this running clock and a standard time, such as UTC, yields a time tag error. This error manifests itself in the positioning process because the recorded time is used to query orbital trajectories and the location of the surface asset in inertial space. If this error is not properly accounted for, it can seriously impact the ability to do position determination. This paper documents analysis on the sensitivity of position determination to time tag errors and approaches for mitigating this error using estimation techniques and observation scheduling.

Current Study Results

This study assumes a simplified scenario, where the only error sources are clock errors, white data noise, and initial condition errors for the surface asset and orbiter. This simplified model aids in isolating the effect of time tag errors, without obscuring it amongst a long list of other errors that must be included in any operational mission. A later study will expand the current results by analyzing time tag errors in the context of a high fidelity model with all significant error sources. Initial results indicate that the positioning problem is relatively insensitive to time tag errors that are induced by clocks derived from ultra stable oscillators (USO).

As an example of the anticipated behavior, consider a tracking scenario between MRO and a lander located at the equator of Mars. Doppler data is collected when the elevation angle at the lander is greater than 15° . The initial error for the lander is 1 km in each component direction, and MRO's initial RSS orbit error is about 50 m, which is conservative considering the performance seen with current Mars orbiters.¹ MRO's USO will have an Allan deviation of approximately 10^{-12} for a 10 second interval. In this case, the clock that is tagging the measurements can be modeled with an error that is a bias, a small drift, and a random walk with strength derived from the Allan deviation of the oscillator. Furthermore, Electra's design is such that the measurement time tagging mechanism that queries the clock does so with an error of under 60 nanoseconds (1σ). The current specification for the Mars Network call for a time reconstruction capability that yields knowledge of network clocks with a bias error of 1 msec,

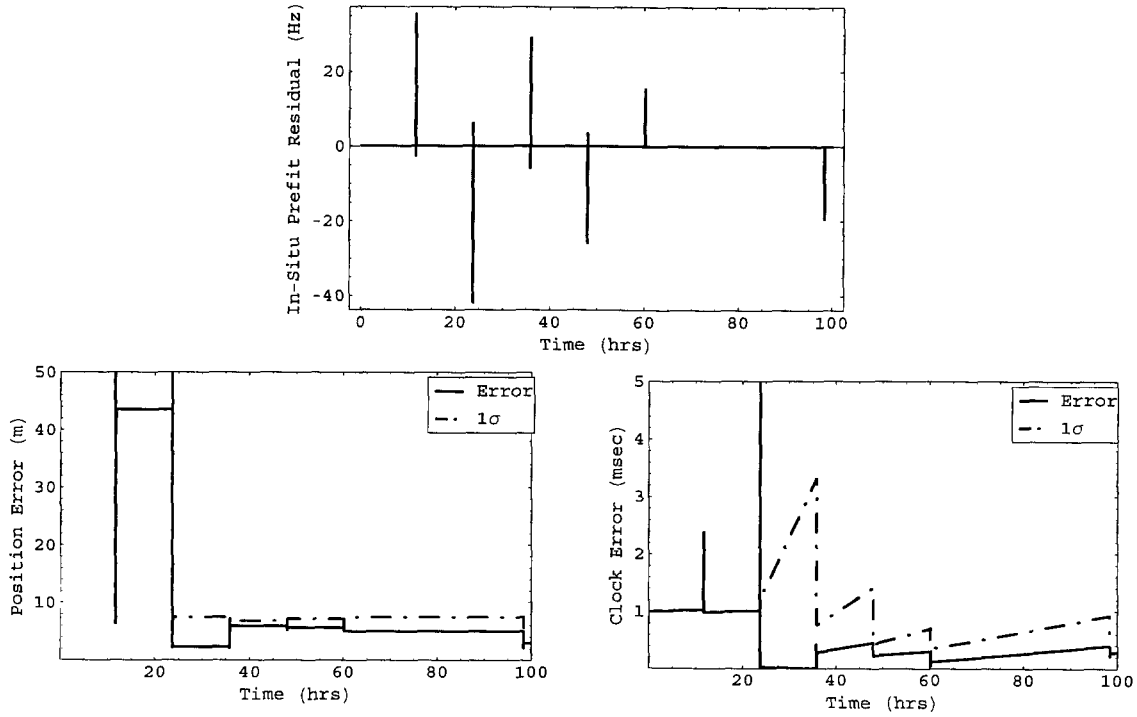


Figure 1: Lander positioning and clock estimation errors for a 100 hr simulation with perfect orbiter trajectory knowledge are shown. The solid lines represent the error between the estimated and true values, and the dash-dot represents the 1σ uncertainty output by the filter. The upper plot shows the times of the tracking passes and the magnitudes of the pre-fit Doppler residuals.

and a clock drift error of 5×10^{-10} . This knowledge is obtained with a separate Mars Network process of clock estimation using time correlation data. These specifications can be used as inputs to the surface asset positioning problem. The estimation algorithm used for this positioning analysis is a Kalman filter that employs a stable UDU factorization with process noise, and has a state vector composed of some or all of the following: lander position components, orbital classical elements, clock bias and clock drift.

In a first example, the only errors are from the lander and clock, the orbiter trajectory knowledge is assumed to be perfect. Errors in reconstruction of the lander position and clock are shown in Figure 1. Note that the upper plot in the figure window shows the time of the tracking passes (which are typically 6 minutes in length) and the magnitude of the Doppler shift during the pass. Clearly, the estimator is capable of determining the lander position to within the required 10 m level with clock errors hover around 1 msec or lower.

Of course perfect orbit knowledge is an idealized case, so in this next example, orbit error and estimation is included as part of the simulation. Results for this are shown in Figure 2. Lander position knowledge is relatively unaffected; the filter uncertainty increases slightly. However, clock estimation is significantly impacted, such that the initial uncertainty never decreases. Additional simulations indicate that the orbiter final covariance and time uncertainty are

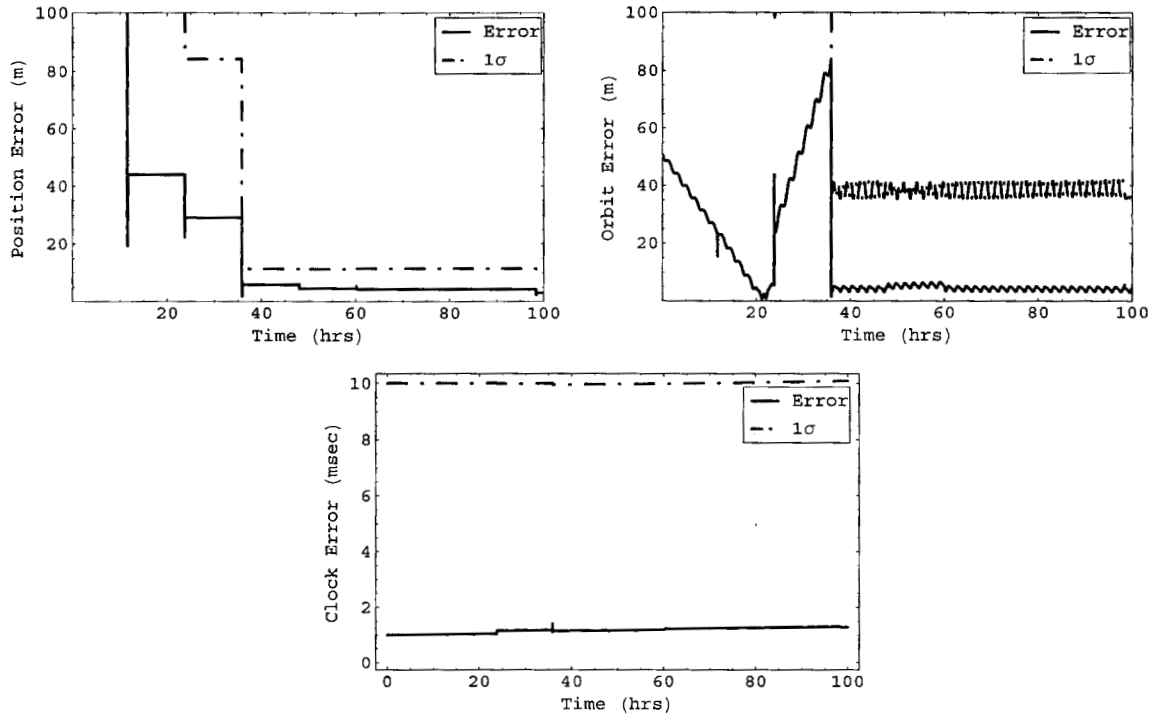


Figure 2: Same case as in Figure 1 except now there is orbit initial condition errors, and the estimator solves for the orbit parameters.

correlated such that the following relationship is observed $\sigma_{orbiter} \sim R_m n \sigma_{clock}$ (R_m radius of Mars, n orbiter mean motion). This is not too surprising, except that the correlations from the output covariance do not suggest this relationship. This is a topic of current investigation.

Improvements in clock and orbit estimation can be obtained by including direct-to-Earth tracking data between the orbiter and an Earth Deep Space Network tracking station. The full paper will present this analysis, plus additional cases investigating sensitivity to parameters, errors, and mismodeling. Furthermore, details on the proposed clock correlation process between a Mars Network orbiter and the Earth will be presented.

Acknowledgements

This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

References

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